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HYBRID MULTIPLE ACCESS TECHNIQUES PERFORMANCE ANALYSIS OF DYNAMIC RESOURCE ALLOCATION

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***Abstract*- The Non-Orthogonal Multiple Access (NOMA) and the Orthogonal Frequency Division Multiple Access (OFDMA) are promising techniques for next-generation wireless systems. Although much attention in the literature considered these techniques, an effective combination between such systems as hybrid multiple access (HMA) needs more attention. For this reason, this paper devotes to proposing two different scenarios of HMA using multi-user OFDM (MU-OFDM) and power domain (PD) NOMA for downlink transmission to overcome the limitations of both Orthogonal Multiple Access (OMA) and NOMA. Due to the randomness of a wireless channel, different user grouping strategies and dynamic power allocation (DPA) strategies are employed to satisfy users' requirements. The proposed systems give high flexibility utilizing bitrate allocation and user fairness. System results show superior performance to traditional OMA and NOMA systems. The achieved variety of fairness is helpful for the diversity of applications which is a principal requirement for beyond-fifth-generation (B5G) networks. The next step in this analysis is to enhance the proposed systems' spectral efficiency (SE) by introducing beamforming for massive Multiple-Input Multiple-Output (MIMO) systems. The bit error rate (BER) result of the proposed system achieves almost the same error floor with a benefit of approximately** 10 dB **signalto-noise ratio (SNR) when 90 resource blocks (RBs) are used.**

keywords: **OMA, HMA, NOMA, MU-OFDM, Resource Allocation (RA)**

I. Introduction

For the increasing demand for user data services in B5G networks, providing massive connectivity and supporting superior data rates is necessary. The requirements of B5G networks for enhanced mobile broadband and massive machine-type communication necessitate the use of creative techniques that support higher SE and user equipment densities. [1]. To achieve such goals, efficient multiple access (MA) techniques have a significant impact. In general, the MA techniques are classified as either NOMA or OMA. The OFDMA, used in some cellular networks as an OMA technique, suffers from low SE as the network density increases [2, 3]. There is bandwidth wastage in OMA since it is based on allocating one orthogonal RB to each user. Furthermore, it has low access efficiency and high signaling overhead. For these reasons, OMA cannot achieve the abovementioned goals [4].

NOMA is a promising MA scheme due to its significant ability to enhance system throughput and SE. With NOMA, two or more users can be served by one RB, and one user can use more than one RB to improve the data rate. In PD-NOMA, superposition coding (SC) is employed at the transmitter to multiplex users' signals, while the successive interference cancellation (SIC) technique is used at the receiver to demultiplex them. The usage of SC can enhance user fairness, sum rate, and scheduling flexibility, while the SIC can be utilized to eliminate inter-user interference [5, 6]. Though, due to non-orthogonality, NOMA is more interference limited than OMA. To successfully decode signals in NOMA, a higher

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SNR is needed. NOMA has no considerable advantage over OMA in low SNR, making it less desirable for users with unsatisfactory channel gains (low SNR) [7, 8].

Recently, considering both orthogonal and non-orthogonal MA transmission advantages into account, the HMA has taken a lot of attention. A hybridization between OMA and NOMA in the same bandwidth with efficient user grouping and RA algorithm provides a tradeoff between achievable data rates, system capacity, and inter-user interference [9].

In [1], a hybridization scheme of OMA and NOMA was proposed. To improve bandwidth efficiency and resource utilization, the authors considered the OMA/NOMA mode selection, the multi-cell environment, and the power allocation. The scenarios were divided into inter-cell and intra-cell NOMA and OMA modes based on an interference map. The suggested HMA focused on identifying the optimal operating method for user pairs to enhance the quality of service (QOS) and the overall sum rate. Compared with conventional OMA, the OMA/NOMA mode selection achieved sum rate enhancement without compromising the QoS demands.

The authors in [7] suggested a downlink HMA scheme for the fifth-generation (5G) networks. For HMA to outperform pure OMA or NOMA, a necessary condition on the users' channel gains was derived. To achieve optimal group size and consequently optimal throughput, an optimization problem was formulated and numerically solved. The throughput and outage performance of the HMA system were compared with traditional OMA and NOMA. However, the inter-user inference is not taken into account in this work.

In [10], a HMA employing OMA and NOMA with RA pattern was proposed. A NOMA group combination was selected as the best resource design considering the highest throughput performance. The throughput results of the HMA system were compared with that of NOMA and OMA.

A fair PA scheme for the traditional PD-NOMA technique was proposed in [11]. The authors developed models for two users and multi-user scenarios. The models were based on coefficient scaling to address the outage issue. System sum rate, outage, fairness index, and BER were evaluated. The fairness results showed a remarkable increase compared to a state-of-the-art PA scheme for the NOMA system.

In [12], a RA scheme for a downlink NOMA system was proposed. Based on maximizing the sum rate, an optimization problem was developed. A sub-optimal solution for a two-user scenario with a satisfactory level of complexity was considered first. Then, the scheme was extended to multi-user by proposing a user pairing mechanism for the NOMA system. Simulation results demonstrated the effectiveness of the suggested approaches.

The above literature confirms the importance of the NOMA technique in 5G and B5G systems due to a need for higher data rates, increasing system capacity, and diversity of user applications. Although some of the above works considered using HMA to overcome some NOMA limitations, the inter-user interference and system SE problems need more attention.

There is an increasing demand to effectively combine NOMA and OMA with the growing number of users and diversity of application requirements. Furthermore, to the best of the authors' knowledge, a RA strategy according to users' requests and channel conditions for those HMA had not been widely considered. The power and RA strategies proposed by some authors in the above literature are concentrated on conventional NOMA rather than HMA.

For those reasons, this paper proposes different scenarios of HMA using NOMA and MU-OFDM to increase the

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achievable users' data rates and reduce the interference due to NOMA. The proposed system provides plenty of RA patterns that give bitrate allocation and user fairness flexibility due to the diversity of applications for B5G requirements.

II. System Model

This paper proposes two scenarios for the downlink HMA using OMA and NOMA simultaneously in the same bandwidth. Due to its robustness to multipath fading channels, multi-user OFDM (MU-OFDM) with flexible numerology of New Radio (NR) is employed to multiplex user's signals based on OMA technique. At the same time, PD-NOMA with SC is used to multiplex users' signals based on NOMA technique. The number of existing users in both systems is set to multi-user to establish the concept of hybrid MA techniques with different user grouping scenarios. The symbols Uf, Um, and Un denote far, middle, and near users, respectively. The two scenarios will be described in the following subsections as HMA-I and HMA-II.

A. *HMA-I*

The transmitter block diagram of the proposed HMA-I system is shown in Fig. 1. To achieve the system design idea, three users Uf, Um, and Un, are employed. Based on the NOMA concept, higher system capacity can be reached when the channel gain difference between users is high. For this reason, according to users' distances from the base station (BS), a pair of users with higher differences in channel conditions (Uf and Un) is selected to form a NOMA group. Then the third user's signal (Um) is orthogonally multiplexed with the NOMA signal using MUOFDM. The composed multicarrier signal is transmitted from the BS to all users through a fading channel. The same grouping strategy can be applied when more than three users are employed.

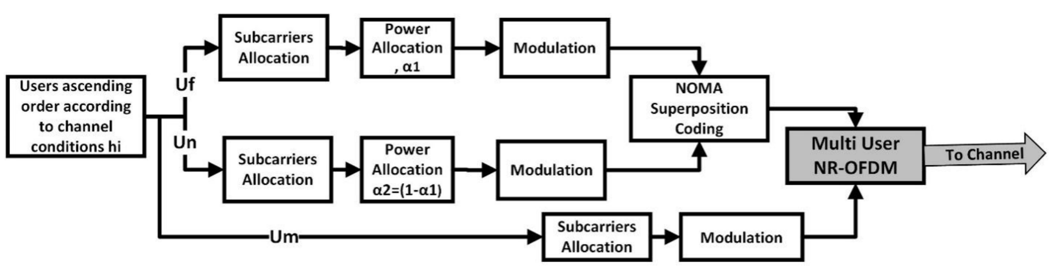

Figure 1: The transmitter block diagram of the proposed HMA-I system

The RA pattern of the proposed HMA-I is illustrated in Fig.2. This RA strategy surpasses the HMA scenario suggested in [10] due to employing a multicarrier technique. As shown in Fig. 2, for a NOMA group signal, more transmission power is allocated to Uf due to poor channel gain, while less transmission power is given to Un, which has good channel gain.

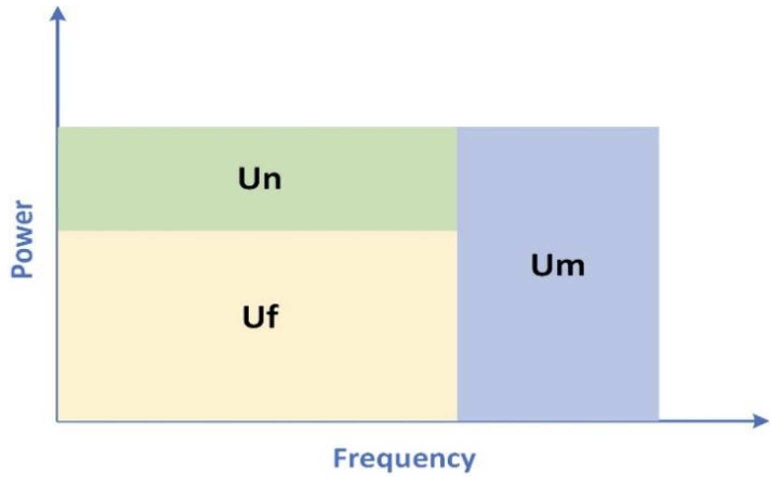

Figure 2: RA pattern of the first proposed HMA

Then to reduce inter-user interference, the NOMA group is multiplexed with Um signal using MU-OFDM. As a combination between OMA and NOMA, the instantaneous channel capacities for all users in the first proposed HMA are given by:

$$R_f^{HMA-I} = W_f \log_2 \left(1 + \gamma \frac{a_f p \left|h_1\right|^2}{a_n p \left|h_2\right|^2 + \sigma_1^2}\right) \tag{1}$$

$$R_m^{HMA-I} = W_m \log_2 \left(1 + \gamma \frac{p \left|h_2\right|^2}{\sigma_2^2}\right) \tag{2}$$

$$R_n^{HMA-I} = W_n \log_2 \left(1 + \gamma \frac{a_n p \left|h_3\right|^2}{\sigma_3^2}\right) \tag{3}$$

Where $W_f = W_n = \frac{2}{3}W, W_m = \frac{1}{3}$ W, W is system bandwidth, γ is the SINR improvement factor due to using OFDM modulation. $\gamma = N/M, N$ is the used data subcarrier, and M is the Fast Fourier Transform (FFT) size. P is the total transmit power from the BS, hi is the Rayleigh fading coefficients, σ_i^2 is the noise variance, a_f and a_n are the power allocation factor assigned to Uf and Un, respectively. To illustrate the enhancement in SINR for each user in the proposed system, as compared with conventional NOMA, the instantaneous channel capacities in NOMA are given by [13]:

$$R_f^{\text{NOMA}} = W \log_2 \left(1 + \frac{a_f p \left|h_1\right|^2}{a_m p \left|h_1\right|^2 + a_n p \left|h_1\right|^2 + \sigma_1^2}\right) \tag{4}$$

$$R_m^{NOMA} = W \log_2 \left(1 + \frac{a_m p \left|h_2\right|^2}{a_n p \left|h_2\right|^2 + \sigma_2^2}\right) \tag{5}$$

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$$R_n^{NOMA} = W \log_2 \left(1 + \frac{a_n p \left| h_3 \right|^2}{\sigma_3^2} \right) \tag{6}$$

Where a_m is the power allocation factor assigned to Um. It can be noticed that the SINR for Uf and Un are increased due to decreasing the interference with other users' signals. Furthermore, all users' SINR is enhanced by the factor γ compared to that of the conventional NOMA and that of the system proposed in [10].

B. ***HMA-II***

In this section, for the same three users, the HMA-II scenario with two different RA patterns is described. Fig. 3 illustrates the transmitter block diagram of the proposed HMA-II system. First, a pair of OMA users is constructed, and the two users' signals are multiplexed together using MU-OFDM. The third user signal is processed to OFDM modulation before multiplexing with other users' signals using NOMA SC.

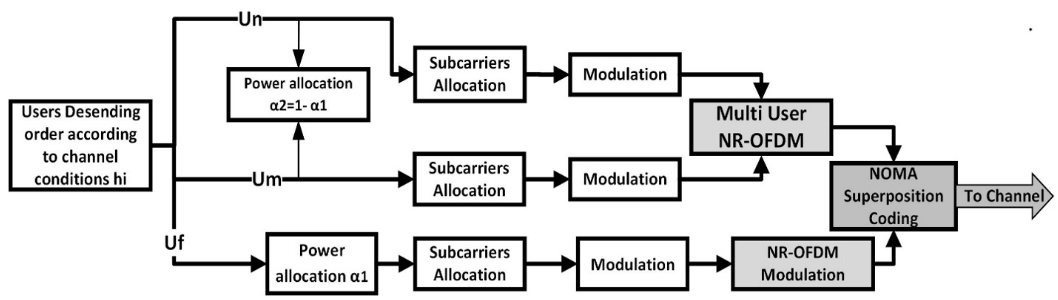

Figure 3: The transmitter block diagram of proposed HMA-II

This system considers two different RA patterns; thus, two different strategies for user grouping are used, as shown in Fig. 4. These two patterns will be denoted as P-A and P-B. The first RA pattern (P-A), established in Fig. 4.a, is suggested to achieve users' fairness.

The instantaneous channel capacities for all users in the proposed HMA-II using P-A for RA are given by:

$$R_f^{HMA-II_{P-A}} = W \log_2 \left(1 + \gamma \frac{a_1 p \left| h_1 \right|^2}{a_2 p \left| h_1 \right|^2 + \sigma_1^2} \right) \tag{7}$$

$$R_m^{HMA-II_{P-A}} = W_m \log_2 \left(1 + \gamma \frac{a_2 p \left| h_2 \right|^2}{\sigma_2^2} \right) \tag{8}$$

$$R_n^{HMA-II_{P-A}} = W_n \log_2 \left(1 + \gamma \frac{a_2 p \left| h_3 \right|^2}{\sigma_3^2} \right) \tag{9}$$

Where $W_m = W_n = \frac{1}{2}W, a_1$ and a_2 are the power allocation factors assigned to far and near users/groups respectively. As compared with the instantons channel capacities of HMA-I described in (1-3), Uf can access the total system bandwidth while Um accesses half of the whole system bandwidth.

The second pattern (P-B) of the RA which is shown in Fig. 4.b is suggested considering the diversity of applications according to users' bitrate. Such variety of users' rates is one of the main requirements of nextgeneration wireless systems. The instantaneous channel capacities using P-B RA are given by:

$$R_f^{HMA-IIP-B} = W_f \log_2\left(1+\gamma\frac{a_1 p\left|h_1\right|^2}{a_2 p\left|h_1\right|^2+\sigma_1^2}\right) \tag{10}$$

$$R_m^{HMA-II_{P-B}} = W_m \log_2\left(1+\gamma\frac{a_1 p\left|h_2\right|^2}{a_2 p\left|h_2\right|^2+\sigma_2^2}\right) \tag{11}$$

$$R_n^{HMA-II_{P-B}} = W \log_2\left(1+\gamma\frac{a_2 p\left|h_3\right|^2}{\sigma_3^2}\right) \tag{12}$$

Where $W_f = W_m = \frac{1}{2}W$. It can be noticed from (12) that Un in HMA-II P-B can achieve a higher data rate than in other scenarios and with another user's rate. This strategy is suggested in this work considering that Un traffic needs a higher data rate.

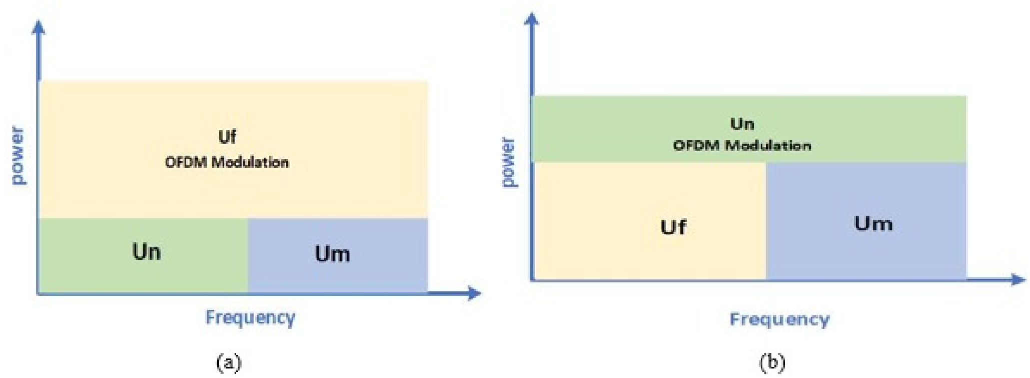

Figure 4: RA pattern of the proposed HMA-II, (a) a pattern for user fairness (P-A), (b) a pattern for applications diversity (P-B)

III. Results and Discussions

The effectiveness of the proposed systems is verified in this section by comparing them with conventional MUOFDM and conventional NOMA. The achievable sum rates of the proposed schemes are shown in Fig. 5. Five designs are considered; the proposed HMA-I, HMA-II-P-A, HMA-II-P-B, conventional NOMA, and OMA. In this case, channel gain values are assumed as 0,10 , and 20 dB for Uf, Um, and Un, respectively. It can be noticed from Fig. 5 that all the proposed scenarios outperform the conventional OMA and NOMA techniques for the common SNR values for mobile systems.

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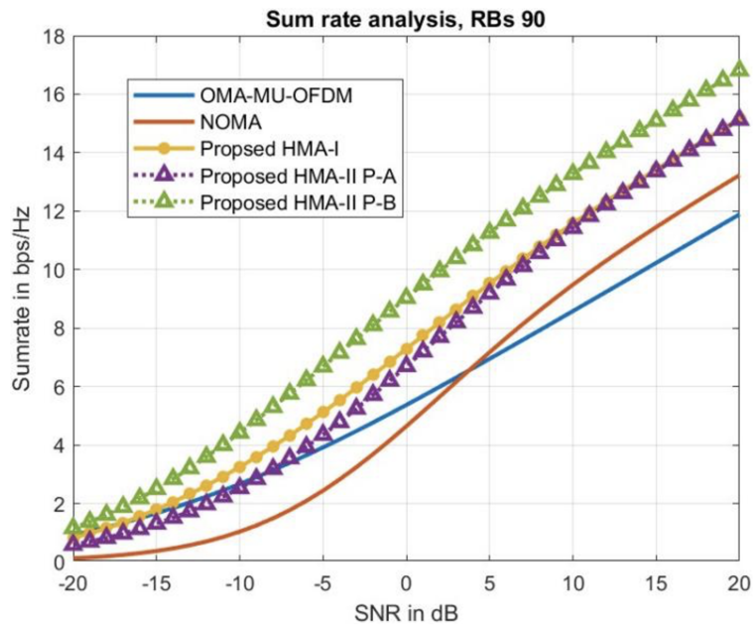

Figure 5: The achievable sum rate of the proposed systems

For low SNR values, even though OMA outperforms NOMA due to lower inter-user interference in MU-OFDM, the proposed schemes either achieve comparable or better sum rate performances in this case. The results show that the achievable sum rate of the proposed HMA-I is increased by 25% and 20% compared with OMA and NOMA, respectively. At the same time, the proposed HMA-II provides an increase in sum rate of 32% and 28% compared with OMA and NOMA, respectively.

The user's data rates for all scenarios are also evaluated, and the results are shown in Fig. 6. The achieved data rate of the proposed HMA-I, HMA-II-P-A, HMA-II-P-B systems are displayed in Figs.6.a, b, and c, respectively. It can be noticed that in all designs, Un gets higher data rates than other users' rates due to channel conditions. But as a comparison between the proposed scenarios, it achieves a higher rate in HMA-II P-B (Fig. 6.c) due to the RA pattern. Such a scenario is practical if different data rates are required due to the diversity of users' applications. PA RA in HMA-II proposed system (as shown in Fig. 6.b) provides comparable data rates between users since the channel condition are considered while allocating resources between users.

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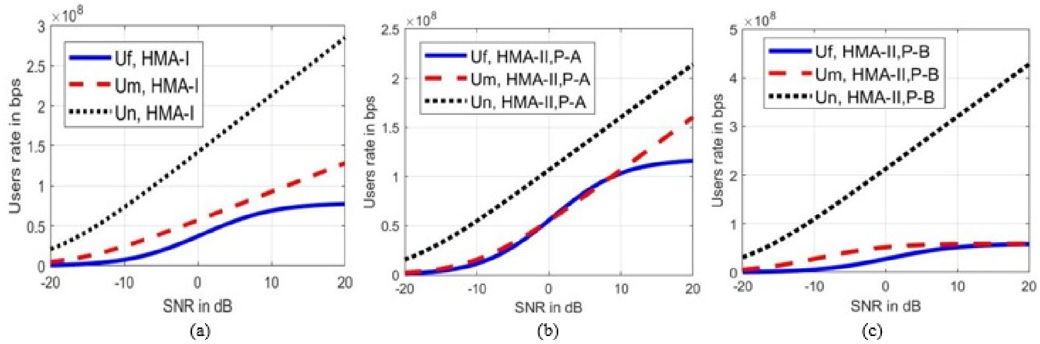

Figure 6: Users Data Rates (a) the proposed HMA-I, (b) the proposed HMA-II P-A, (c) the proposed HMA-II P-B

To evaluate how well the resources are allocated between users in the different proposed scenarios, Jain's fairness index (K) is measured as follows [11]:

$$K = \frac{\left(\sum_{i=1}^{L} R_i\right)^2}{L\sum_{i=1}^{L}\left({R_i}^2\right)} \tag{13}$$

Where R_i represents the rate of a specific user, and L is the number of users. The above expression gives unity when all the users have the same rate in the system. The results of user fairness for the proposed systems according to (13) are shown in Fig. 7. It can be seen that the proposed systems outperform conventional NOMA in user fairness. The used P-B RA of the HMA-II system gives a lower user fairness because the highest channel gain user (Un) is assigned all the system bandwidth due to the NOMA concept. Such a scenario is useful when a user needs a higher data rate due to its traffic requirement, such as a high-definition video application. At the same time, the decoder of this system has less complexity since Uf and Um can decode their data without SIC.

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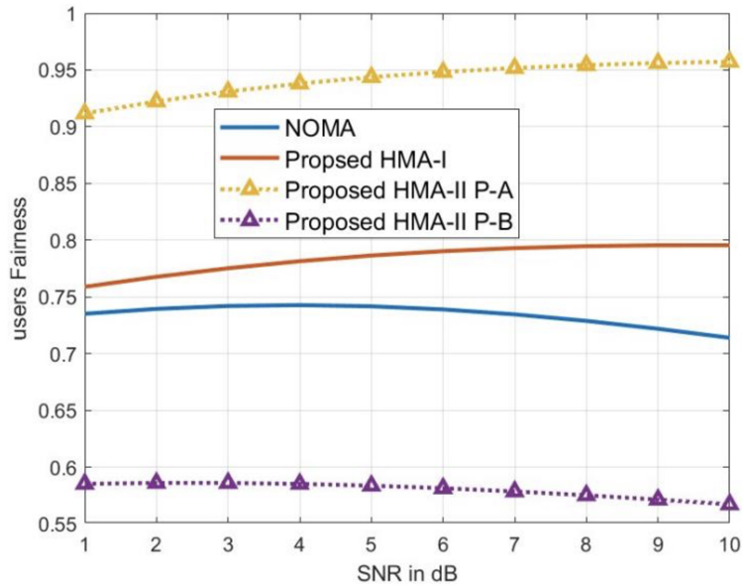

Figure 7: Users fairness of the proposed systems

In the above system analysis, constant channel coefficients are assumed. To consider a more realistic scenario and due to channel randomness, another system analysis is considered. This analysis generates Rayleigh coefficients randomly according to user distances from the BS. Fixed and dynamic power allocation are employed in this scenario. The DPA algorithm used in [11] for the conventional NOMA system is applied for both HMA-I and HMA-II systems. Table I shows the system simulation parameters in this case. Fig. 8 displays the sum rate of the proposed scenarios using DPA and fixed power allocation (FPA). When DPA is used, the sum rates of all the proposed schemes give further enhancement.

TABLE I
System simulation parameter using random channel coefficients

Simulation Parameters	
Distances (meters)	$5000, 3000, 1000$
Path loss	4
Pt (max)	30dBm
FFT size	4096
RBs	90
Noise Density (No)	-114dBm

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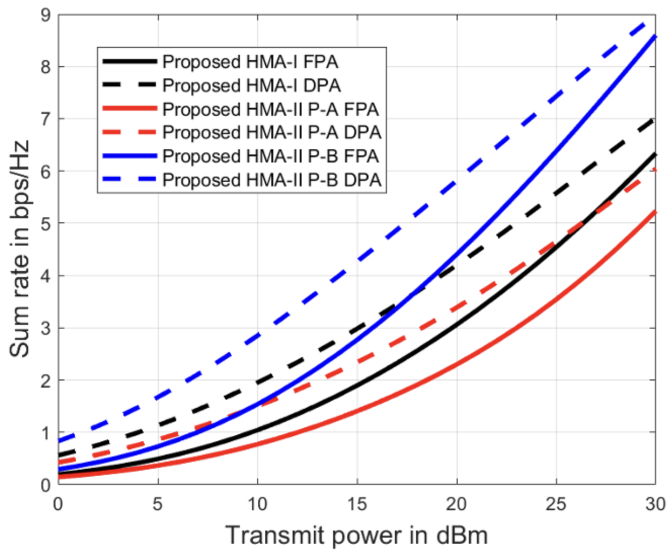

Figure 8: Sum rate using DPA with Random channel coefficients

The BER results of the proposed systems are shown in Fig. 9. It can be seen from Fig. 9.a that Um in the HMA-I system has a smaller BER than Un and Uf. Since Um accessed the channel orthogonally using MU-OFDM, it has a higher SINR due to less inter-user interference value. Furthermore, Uf and Un are multiplexed together using NOMA; they have higher BER due to higher inter-user interference.

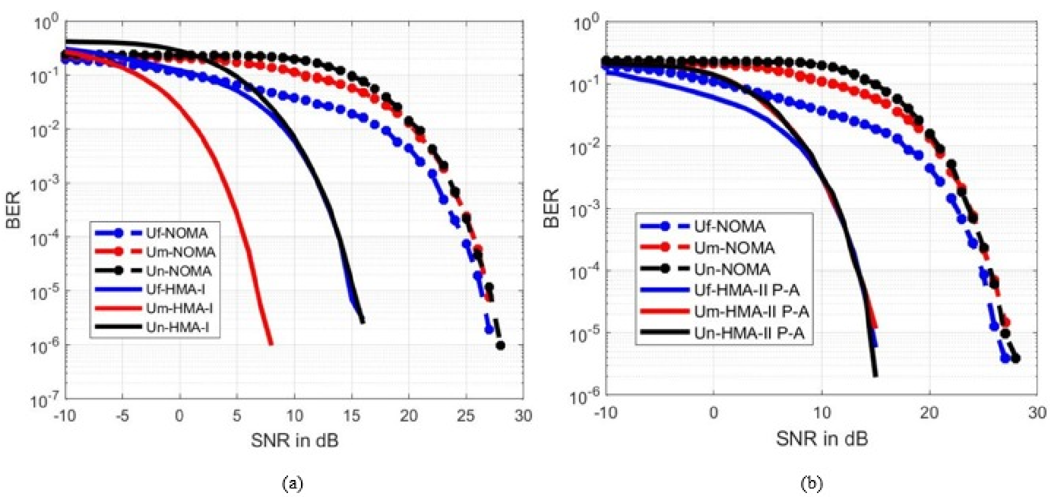

Figure 9: BER of the proposed systems, (a) the proposed HMA-I, (b) the proposed HMA-II

The BER results of the proposed HMA-II system are shown in Fig. 9.b. In this system, since OMA group users accessed the channel with the third user based on the NOMA concept, all users have comparable BER performance. Compared with the HMA-I system, the BER of Um is higher due to inter-user interference because of the non-orthogonality. For both scenarios, as compared with NOMA, the BER for each user is reduced successfully due to multicarrier modulation, which diminishes the inter-user interference.

The total number of used RBs is set to 90 for all of the above results. In the HMA-I system, according to the RA pattern shown in Fig. 2, 60 RBs (720 subcarriers) are assigned to the NOMA group (Uf and Un), while Um uses 30 RBs (360 subcarriers). While in the HMA-II system, according to the RA pattern shown in Fig. 3. b, 15 RBs (180 subcarriers) are assigned to the OMA group (Uf and Um), while Un uses 30 RBs (360 subcarriers).

IV. Conclusion

This paper proposes two different downlink scenarios for HMA as a combination between OMA and NOMA. Different user grouping strategies with the DPA algorithm are employed to achieve a variety of users' data rates. The results show that the proposed HMA systems outperform conventional NOMA and MU-OFDM systems regarding capacity and user rates. The achievable sum rate is improved by approximately $20-25\%$ compared to the MU-OFDM systems and by $28-32\%$ compared to conventional PD-NOMA. The high BER of the NOMA system due to the inter-user interface is also decreased in the proposed systems. Different user grouping strategies are established, which provide different convenient scenarios which can be used for various applications based on users' bitrates. An exciting extension to this work is incorporating the massive MIMO beamforming techniques with the proposed scenarios to achieve higher SE. Furthermore, as it's clear from our analysis of different systems, forward error correction is not considered in the design. We concentrate on multiple access mechanisms; if error correction is used, further enhancement in BER performance can be satisfied.

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CONFLICTS OF INTEREST

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REFERENCES

[1] A. Ebrahim, A. Celik, E. Alsusa, and A. M. Eltawil, "NOMA/OMA Mode Selection and Resource Allocation for Beyond 5G Networks," in *2020 IEEE 31st Annual International Symposium on Personal, Indoor and Mobile Radio Communications*, London, UK, 2020.

[2] H. Mathur, and T. Deepa, "A Survey on Advanced Multiple Access Techniques for 5G and Beyond Wireless Communications," *Wireless Pers Commun*, vol. 118, no. 2, pp. 1775–1792, 2021.

[3] A. A. Abdulhussein, and H. N. Abdullah, "PERFORMANCE EVALUATION OF FILTER BANK MULTI CARRIER MODULATION IN MULTIPATH FADING CHANNELS," *Iraqi Journal of Information and Communications Technology (IJICT)*, vol. 1, no. 1, pp. 1:10, 2021.

[4] I. Budhiraja, et al, "A Systematic Review on NOMA Variants for 5G and Beyond," *IEEE Access*, vol. 9, pp. 85573–85644, 2021.

[5] A. H. Tacuri, J. Maldonado, M. Revollo, and H. Chambi, "Bit Error Rate Analysis of NOMA-OFDM in 5G Systems With Non-Linear HPA With Memory," *IEEE Access*, vol. 9, pp. 83709–83717, 2021.

[6] Shahen Shah, A. ,Qasim, A, M., Karabulut, M, A., et al., "Survey and Performance Evaluation of Multiple Access Schemes for Next-Generation Wireless Communication Systems," *IEEE Access*, vol. 9, pp. 113428–113442, 2021.

[7] A. Anwar, B. C. Seet, and X. Li, "Hybrid multiple access for 5G downlink systems: Throughput and outage analysis," *International Journal of Electronics and Communications*, vol. 117, pp. 1-5, 2020.

[8] M. Vaezi, Z. Ding, and H.V. Poor, *Multiple Access Techniques for 5G Wireless Networks and Beyond*, Manchester: Springer, 2019.

[9] M. Ahmad, I. N. A. Ramatryana, and S. Y. Shin, "NOMA and OMA Comparison for Multiple Antenna Technologies under high Capacity Constraints for 5G and Beyond," *The Journal of Korean Institute of Communications and Information Sciences*, vol. 45, no. 11, pp. 2004–2013, 2020.

[10] F. Tanaka, H. Suganuma, and F. Maehara, "Hybrid Multiple Access Scheme Using NOMA and OMA Simultaneously Considering User Request," in *2021 24th International Symposium on Wireless Personal Multimedia Communications (WPMC)*, Okayama, Japan, 2021.

[11] S. Srivastava and P. P. Dash, "Coefficient-Scaling-Based Fair Power Allocation for Multi-User Power-Domain Nonorthogonal Multiple Access Network," *Journal of Circuits, Systems and Computers*, vol. 30, no. 16, pp. 1–22, 2021.

[12] Z. Q. Al-Abbasi, and D. K. C. So, "Resource Allocation in Non-Orthogonal and Hybrid Multiple Access System With Proportional Rate Constraint," *IEEE Transactions on Wireless Communications*, vol. 16, no. 10, pp. 6309–6320, 2017.

[13] B. C. K. Talla, O. V. Bossou, C. Feudjio, J. N. Mbogue, G. N. Ngoufo, and R. Tchuidjan, "A new approach of successive interference cancellation decoder in power domain non-orthogonal multiple access transmission," *Wireless Networks*, vol. 9, pp. 509–521, 2022.

